Extraterrestrial Life: Lecture #21

Homework #5 is due Thursday (limited office hours this afternoon, but I will be available all tomorrow afternoon if you have queries)

Last time discussed *radial velocity* method for finding planets - very good for finding massive planets

How can we find *habitable* planets (Earth mass, in roughly Earth-like orbits)?

Transits

As seen from Earth, both Mercury and Venus occasionally *transit* the face of the Sun:

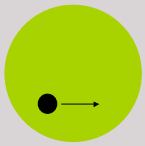
Transits of Venus are rare: occur in pairs every ~200 years (next one in 2012)

Transits

If an extrasolar planet transits its host star as seen from Earth, cannot resolve the disk of the star and directly see the transit

Instead, measure the reduction in the starlight caused by the transiting planet blocking light from a fraction of the star's surface (i.e. see a very partial eclipse of the star).

Magnitude of the transit signal



Fraction of the starlight blocked is just the fraction of the stellar disk that is covered - i.e. the ratio of the area of the planet disk to the stellar disk.

Planet has radius R_p, star has radius R_*

Fractional drop is:

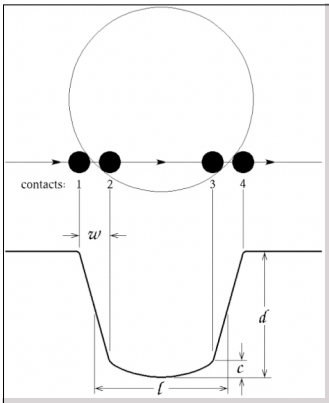
$$f = \frac{\pi R_p^2}{\pi R_*^2} = \left(\frac{R_p}{R_*}\right)^2$$

Sun's radius is 6.96×10^8 m
Jupiter's radius is 7.14×10^7 m
Earth's radius is 6.4×10^6 m

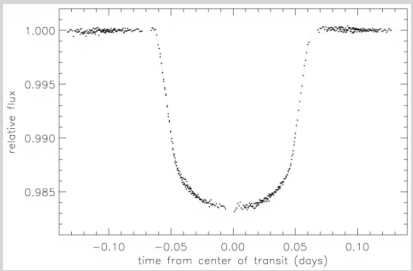
$$f = \left(\frac{R_p}{R_*}\right)^2 = \left(\frac{7.14 \times 10^7 \text{ m}}{6.96 \times 10^8 \text{ m}}\right)^2 = 0.01$$

The signal for a Jupiter radius planets is ~1% drop in the stellar light during the transit - this is large enough to see from the ground.

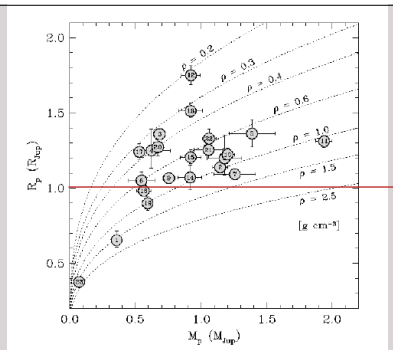
For Earth, $f = 8 \times 10^{-5}$ or 0.008% - cannot be detected from the ground due to variations in the atmosphere but should be detectable from space.



Relation of the light curve to the geometry of the transit



Numerous hot Jupiters have now been discovered via searches of many stars for transits - provides a measurement of the planetary radius and, if the mass is known from radial velocity measurements, the planetary density.

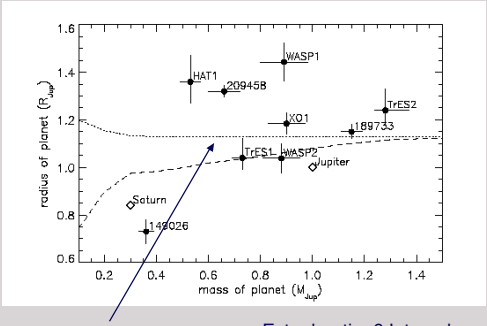


Radii of known transiting planets

Results show that the hot Jupiters have densities of around 1 g cm^{-3} (1000 kg m^{-3}) similar to water… and to the densities of Jupiter and Saturn.

Demonstrates that the hot Jupiters are gas giants rather than very massive rocky planets.

Puzzle: some (but not all) of the hot Jupiters have a radius that is too large compared to models for giant planet structure - what is going on?

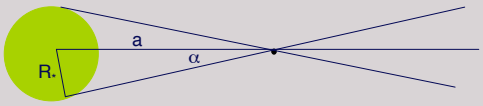


theoretical models

Extra heating? Internal structure different?

Transit geometry

Orbit needs to line up accurately with the line of sight to the star for us to see transits - how likely is that?



The angle α is given by: $\sin\alpha = \frac{R_*}{a}$

…where R_* is the stellar radius and a the radius of the planetary orbit. See transits within an angle α of the exactly edge on case.

If the orbits of extrasolar planetary systems are randomly inclined to our line of sight, the chance of seeing a planetary transit works out to be:

$$P_{transit} = \frac{R_*}{a}$$

Probability decreases for further out planets (also have to monitor the star for longer since only one transit occurs per orbit)

For the Earth, $R_* = 6.96 \times 10^8$ m, a = 1.5×10^{11} m

$$P_{transit} = \frac{6.96 \times 10^8 \text{ m}}{1.5 \times 10^{11} \text{ m}} = 0.005$$

about 0.5% chance of seeing a transit if we look for one year

Kepler search for habitable planets

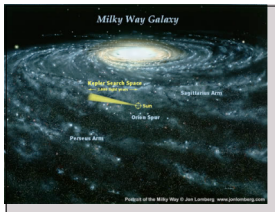
Requirements for a transit search for habitable planets:

- precision - need to measure stellar flux to 1 part in 10^5 to see the transit signal for an Earth radius planet… thought that this is technically possible
- duration - need to observe continuously for several years to see multiple transits of the same planet
- number of stars - need to observe many stars simultaneously to have a good chance of seeing planets

Kepler search for habitable planets

NASA's *Kepler* mission is being assembled at Ball aerospace for a launch in Feb 2009

First attempt to detect Earth radius planets in the habitable zone around other stars

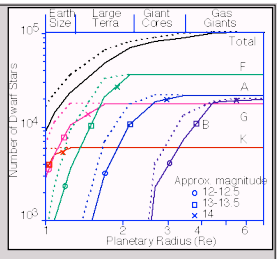


Stare continuously at a single star field containing about 230,000 stars a few thousand light years from the Sun

Around half will be binaries or otherwise unlikely hosts for detectable habitable planets - about 100,000 candidates

About 10,000 will be bright enough that *Kepler* will be able to detect transits of Earth radius planets - **if** the stars have variability similar to the Sun…

If *every* star like the Sun has an Earth radius planet in the habitable zone, expected number of habitable planets found will be:



$$N = \text{number of stars bright enough} \times \text{fraction showing transits}$$
$$= 10^4 \times 0.005$$
$$= 50$$

Might detect many more if larger radius planets (super-Earths) are common, or many fewer if most planets are Mars sized…

Likely to be surprised again… but if nothing goes wrong (!) should know the fraction of stars that have Earth-like habitable planets within a few years time!

Can we determine if `habitable' planets actually host life?